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Changes in climate are major factors shaping the history of human occupance in the Great Plains region. Although Americans have often acted as though climates are fixed, the record indicates that in the past the climate of the Great Plains has changed drastically over relatively short periods of time. In order to acquire some understanding of what the Great Plains climate may become in the future and how human society may prepare for it, we must first comprehend what it was at various times in the past.

CHINOOK CLIMATES

An important element in the climate of the American West is the presence and variability of "chinook" winds--streams of Pacific air that flow eastward over the mountains and plateaus and descend upon the Great Plains, where they create "chinook climates." These air movements are best understood in terms of unique topographical features.

Americans have long understood that the special North American pattern of great mountain ranges (cordillera) athwart the midlatitude westerlies dominates the climate of most of the continent, including areas far to the east of the Rockies. Lorin Blodget first pointed out in 1857 that the West is primarily a high plateau with mountain ranges that modify the flow of air across its surface.[1]

In general, the region is too high to allow most of the moist low-level air impinging on the West Coast to pass over to the plains. The kinetic energy of the west winds is usually insufficient for the air to rise from near sea level to the crest of the Sieras and Cascades. However, much more air leaves the east side of the cordillera near the ground than arrives at the West Coast near the sea.[2] The excess comes from atmospheric levels near the height of the plateau (about four to five thousand feet above sea level). Because of the location of the mountain ranges and the character of the air, there are three dominant routes by which this midlevel Pacific air crosses to the plains--the southern, middle, and northern routes.[3] The three major railroads to the West were built

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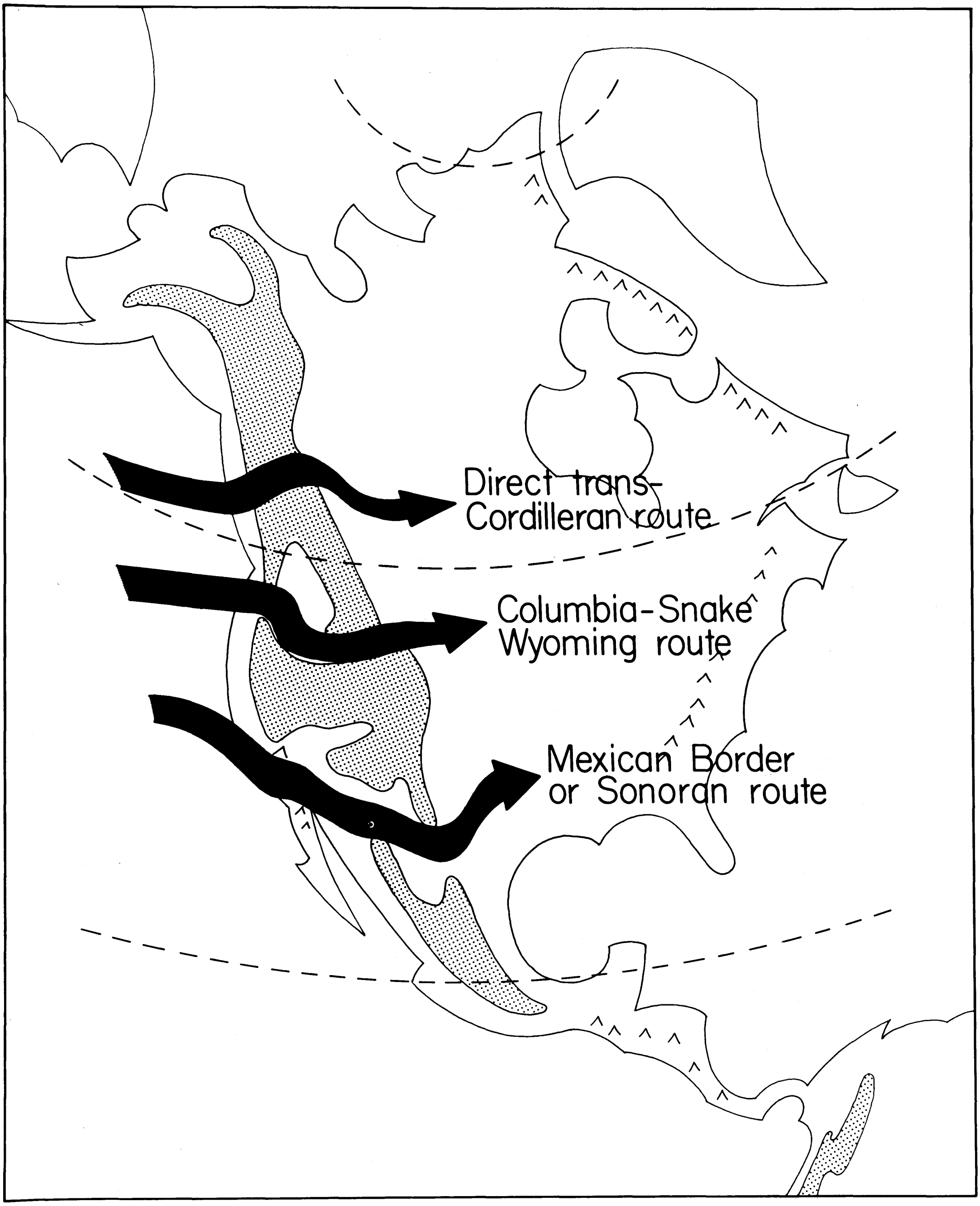

FIG. 1. *Schematic diagram of the cordilleran plateau and the three major low-level trans-cordilleran airstream routes. The stippled area is roughly that which exceeds 5,000 feet in elevation. Source: Reid A. Bryson and F. Kenneth Hare, eds.,* Climates of North America *(Amsterdam: Elsevier, 1974).*

along these routes to take advantage of the least difficult general passages through the cordillera (Fig. 1).

The southern route, which runs roughly along the Mexican border, carries the most air in winter when the westerlies are far south. This air, passing over the southwestern desert and south of the Rockies, flows across the Llano Estacado or northward along the Front Ranges roughly as far as Denver. It is seasonally hot and very dry as it descends from the cordillera down the slope of the high plains.

The middle route for the eastward passage of Pacific air is the broad, lower area of the Columbia River valley, the Snake River area of southern Idaho, and the break between the southern and northern Rockies represented by the basins of Wyoming. This route is at a latitude near that of maximum westerlies, and the mild, dry airstream that flows eastward roughly parallel to the Union Pacific route can often be traced eastward into Ohio and Pennsylvania. It is this dry airstream that coincides with the most easterly extension of the western grasslands—the "prairie peninsula."[4]

The northern route across the Canadian Rockies has no broad system of passes through which lower-level air can flow, but the lower static stability of the Pacific air at Canadian latitudes combined with the strength of the westerlies makes it possible for rather low-level Pacific air to cross the mountains. On the eastern slopes this air is dry and mild in temperature for its latitude, even in winter.

The eastern half of North America, with its broad Hudson Bay–Mississippi Valley system of lowlands, is open to the unimpeded north-south flow of cold Arctic air southward, or warm, moist, tropical air northward. It is between these two extreme types of air that the west winds drive a wedge composed of the three modified varieties of Pacific air.

The seasonal dominance and interplay of these air types define the climatic regions of North America and put a broad set of controls on the distribution of biota and crops. The variation in duration of the dominance of the various airstreams is at the heart of the matter of climatic change.

Occasionally the air flow from the West is able to top the mountain ranges and sink down the leeward, eastern slope. As it descends it compresses, heats, and dries to produce a dramatic phenomenon known as a chinook. Its character is recognized by nearly every westerner. Of a milder nature but on a broader scale, the three Pacific airstreams also become warm and dry as they descend the western plains. The regions affected by these winds have chinook climates; they consist chiefly of the grasslands of North America (Fig. 2).

In the past the depth of incursion of southern and western moisture-bearing airstreams has varied, thereby changing the quantity of moisture available to the rain- or snow-bringing meterological processes. These changes have influenced the character of the West ever since the time of European contact and continue to affect us today.

THE WESTERN CRISIS OF THE TWELFTH CENTURY

In midsummer, near the end of June, the west winds of the middle latitudes shift northward or contract into a smaller vortex about the North Pole. With this change the moist tropical air penetrates more readily northward over the plains and extends into the southwestern United States as well. This event raises the humidity, initiates the summer rains of the Southwest, and provides midsummer showers on the northern plains.[5] At the same time the cyclonic storms of the westerlies shift northward and diminish, decreasing the rains of the Pacific Northwest and moving the warm chinook zone northward to flow across the spruce forests of Canada.

In winter, a rather shallow layer of cold air pours southward from the Arctic, filling the central lowlands on the average up to about the 2,500-foot contour along the edge of the northern plains. The westerlies then are farther south, and more dry air moves eastward through Wyoming and south of the Sangre de Cristo.

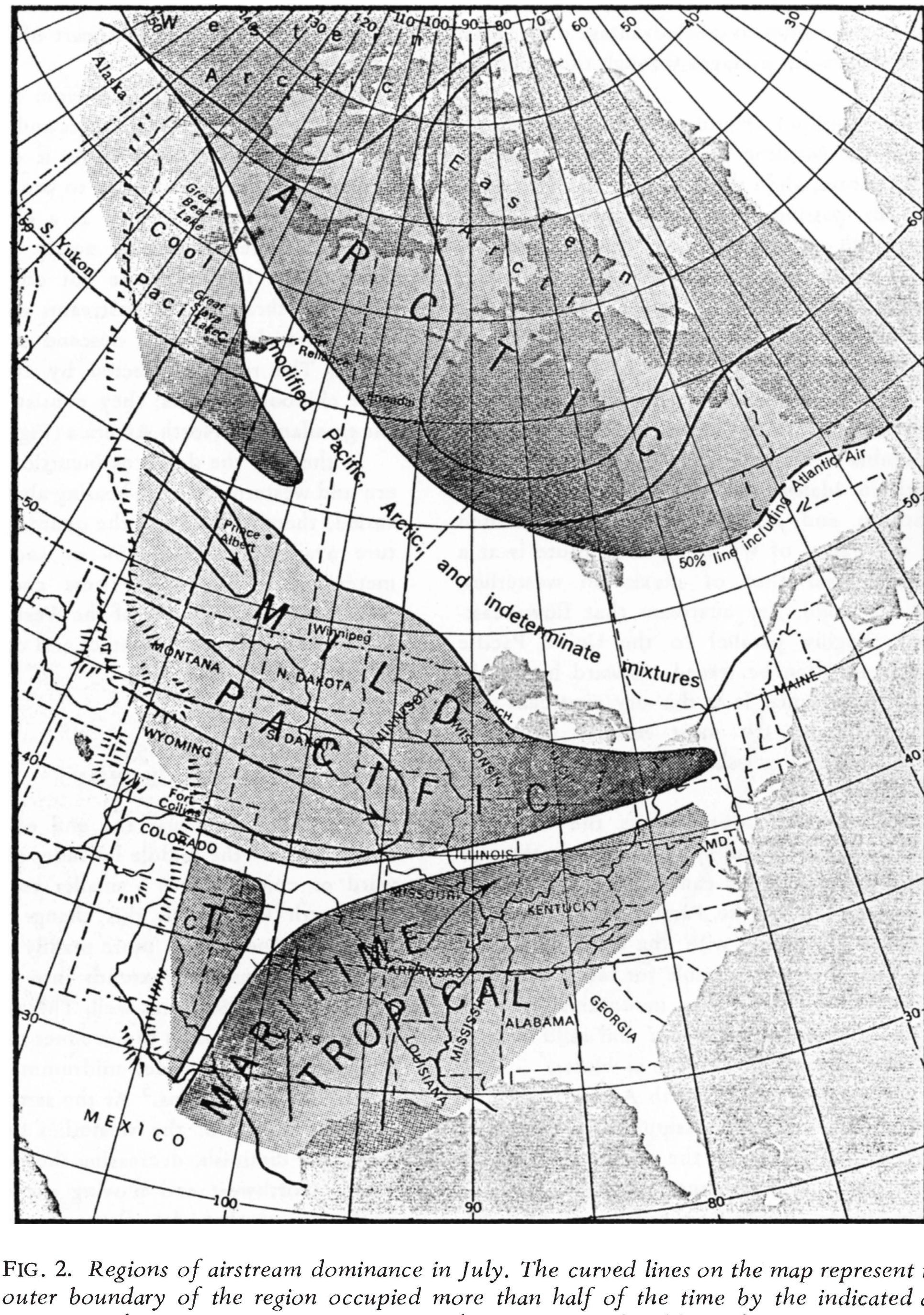

FIG. 2. *Regions of airstream dominance in July. The curved lines on the map represent the outer boundary of the region occupied more than half of the time by the indicated airstream. Within major airstream regions such as Arctic and Mild Pacific, regions occupied more than half of the time by specific subtypes of the major airstreams are also outlined (e.g., Eastern Arctic and Cool Pacific). The regions dominated by "mild Pacific" and "cT" airstreams may be called chinook climates and are primarily grasslands. Source: Reid A. Bryson, "Airmasses, Streamlines, and the Boreal Forest,"* Geographers Bulletin *8 (1966): 228-69.*

During those periods in earth history that are cooler or more winterlike, the Arctic air reaches farther south in summer, and the westerlies also are farther south and stronger.[6] In warmer periods the Arctic air occupies a more restricted region, and the westerly wedge of chinook climates is farther north, as are the thundershowers derived from tropical air streaming northward.

Just as the upper tree line in the Rockies is largely determined by temperature and the lower tree line by dryness, so the northern tree line of the evergreen boreal forest of central Canada is bounded by year-round, cold Arctic air and the southern tree line by the year-long dryness caused by chinook air dominance. One should expect that the shifting of airstreams from one century to another will make dramatic changes in the economic base of tundra, boreal forest, and plains peoples. Such north-south shifts in bioclimate might be two thousand times as large as the up and down shifts of the montane forest.

My own investigation of this phenomenon resulted from a serendipitous event. One day in the early 1960s my field partner and I took off from Lynn Lake, Manitoba, in an overloaded float plane, heading north beyond the tree line to do some research. We unknowingly hit a rock as we left shore and one float compartment quickly filled with water. Needless to say, our takeoff was nearly unsuccessful, but once the water drained out the aircraft flew fairly well and we continued north. After landing, the float refilled with water and the damage became obvious.

Repairs in the bush are not easy, especially amid swarms of mosquitoes and black flies,

FIG. 3. *An example of fossil forest layer under tundra soil, Ennadai Lake, District of Keewatin, Canada. The upper layer is a brown tundra soil that developed in windblown sand. Below it is a thin, dark stratum that consists of carbonized spruce needles and cones dating from shortly before A.D. 1200. Just below the carbon layer is a light zone from which iron has been leached to give a rusty color to the soil below it. Photograph by Reid Bryson.*

but with a piece of rubber boot, some scrap aluminum, and some bolts, we managed to patch the damaged float. Exhausted from these labors, I sat on the float and stared at the shore, where I saw clearly in the wave-cut cliff a fossil soil that I had passed a number of times without noticing. This discovery led to exploration of fossil soils over an area of more than 150,000 square miles.

In the course of these investigations, my colleagues and I uncovered soils that recorded north-south excursions of the northern forest border as much as two hundred miles along a line from Churchill to Great Bear Lake.[7] Radiocarbon dating of the soils showed that the forest had been far north of its present limit more than 3,000 years ago, retreated abruptly southward, was near its present position 2,000 years ago, then advanced fifty to sixty miles farther north until the late twelfth century. An abrupt southward shift of the forest border around A.D. 1200 meant an expansion of the realm of Arctic air and a change in the pattern of the westerlies farther south.

Examination of data from various sources corroborates the story of the fossil soils. The extent of sea ice and cold famine years in Iceland, written records from Europe, pollen data from the Midwest, and glacial data from other places all record a cooling at high latitude and a southward shift of the westerlies.[8]

What happens when the westerlies of summer move farther south, and how is this historic event pertinent to a discussion of the American West? The answer requires the use of archaeological evidence in addition to careful reasoning about climatic change.

Our investigations first centered on finding an explanation for the fact that a large number of villages scattered across the western plains nearly to the base of the Rocky Mountains had been abandoned. The Indians who had inhabited them, known among archaeologists as the Small Village Horizon, had practiced a rain-fed corn agriculture. After A.D. 1200, however, they deserted their villages, the remnants of which were subsequently covered with windblown dust.[9]

In our reconstruction of the summer rainfall change that accompanies the increased strength of the summer westerlies in the middle latitudes, David Baerreis and I used modern data to produce Figure 4. It shows that there is a dramatic decrease of midsummer rainfall on the northern and central plains, the Northwest, and large areas of the Southwest.[10] This is accompanied by a slight expansion of the Arctic area and a minor increase in the strength of the westerlies in the latitudes of the United States. The reconstruction for the West Coast shows more rainfall, but a doubling of July precipitation on the West Coast still does not constitute much rain.

In order to verify our reconstruction of what happened in the twelfth century, Baerreis and I undertook a series of excavations at various sites of the Mill Creek Culture in northwestern Iowa where the occupation of the villages appeared to continue after A.D. 1200. The evidence consistently pointed to a substantial environmental change from prairies with riparian woodlands to steppelike conditions with far fewer trees than before. The meat diet of the Mill Creek people also changed, with a dramatic reduction of deer (woodland browser) and an increase of bison (short-grass grazer).

We concluded that the twelfth century marked the beginning of a two-century-long period of frequent, severe drought on the northern plains. On the high plains, where agriculture was marginal, the drought terminated the life-style of the Small Village Horizon. Farther east the Mill Creek people managed to survive through most of the two centuries, but with a highly modified economic base.

As another check on the validity of our reconstruction we investigated several agricultural villages of the Texas and Oklahoma "Panhandle Aspect." They were located in a region that should have had an increase of 30 to 50 percent in July rainfall. We hypothesized that these villages (which were of uncertain age) were occupied only after the onset of the drought farther north.[11] Radiocarbon dates supported the hypothesis. Moreover, archaeological evidence suggested that the people living

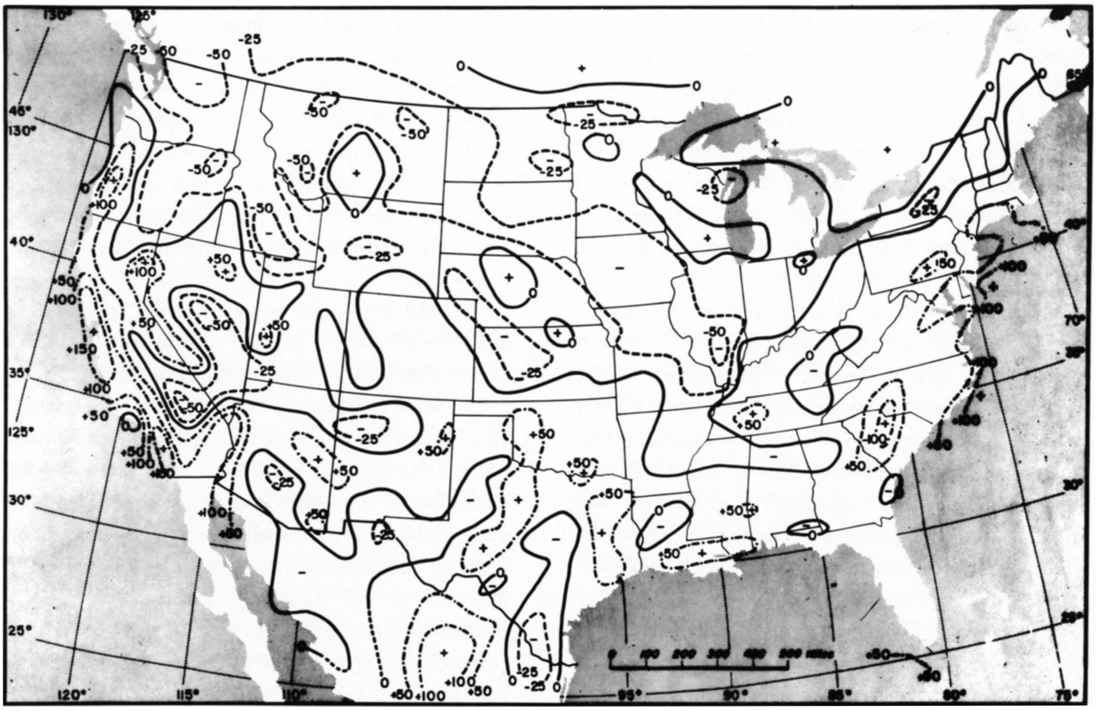

FIG. 4. *Percentage change of July precipitation from periods with very weak westerlies across the United States to periods with stronger westerlies (i.e., a somewhat expanded circumpolar vortex). This should approximate the change from before A.D. 1200 to after A.D. 1200. Source: David A. Baerreis and Reid A. Bryson, "Climatic Change and the Mill Creek Culture of Iowa, Part 1,"* Journal of Iowa Archaeological Society *15 (1968).*

in the drought-striken part of Nebraska on the upper Republican River had moved to the Panhandle region.

Our map also showed a complex pattern of changed rainfall in the Southwest. Numerous studies of this region have revealed that a disruption of occupation patterns, a reduction of occupied area, and strong cultural modification occurred in the twelfth and thirteenth centuries.

Our investigation of late twelfth-century phenomena have implications for the future. The rainfall pattern of the summer of 1974 strongly resembles the pattern of the thirteenth century. Since what has happened in the past can happen again, we must seriously consider whether we are at the beginning of a very long period of drought or at the end of a short period.

THE "LITTLE ICE AGE" AND RESETTLEMENT

The droughts of the thirteenth and fourteenth centuries changed the West in ways that may still be perceived today. The nomadic hunters who replaced the western villagers of the earlier era were partly Athabascans—northern people—as might have been expected with the expansion of the Arctic Zone. The Pueblo cultures of the Southwest also changed. The great period of the Anasazi was over and the area of their occupation was drastically reduced. The same was true of the Mogollones. Only the Hohokam remained approximately as extensive as before, probably because of their irrigation systems.[12]

Shortly before the arrival of large numbers of Europeans in North America in the sixteenth century, another hemispheric climatic change occurred. The first phase of hemispheric cooling following the medieval warm period occurred about 1200 A.D.; the second step into the "Little Ice Age" was largely completed by 1600 A.D. Arctic ice expanded, many glaciers grew, and the price of wheat skyrocketed in Europe.[13] The West also experienced change.

We can be fairly specific about certain features of this new climatic situation because it continued into the period of scientific observation and ended near the beginning of the twentieth century. In order to understand the changes that occurred we must consider a few more details about the behavior of the atmosphere during such changes, particularly the development of north-south meandering of the high-altitude westerly winds. When the hemisphere chills, most of the cooling is in the Arctic and Subarctic. This is associated with an expansion of the west winds toward the equator, like the expansion around A.D. 1200. However, further expansion (with further cooling) extends the west winds far enough into the tropics that a phenomenon called "dynamic instability" occurs. The upper-level west winds, instead of flowing eastward with gentle north-south undulations, frequently break into great loops. In these loops tropical air may be carried far into the Arctic and Arctic air far into the tropics.

Most important for climate is the fact that these big loops are slow-moving. In fact, meteorologists often refer to such situations as "blocking." We know from both reconstructions and direct scientific observation that such situations were far more common during the Little Ice Age than in the twentieth century.[14] These blocking loops tend to be located over certain geographical areas, such as a northward loop located over the cordillera. As a consequence strong west-east contrasts of climate can develop.

During the seventeenth century the climate of the hemisphere was as cold as it had been at any time in the preceding millenium. The English colonists of the 1620s and 1630s could hardly have chosen a worse time to settle in America. In Europe, however, the climate had also turned cold. Summers were wet and winters were cold—conditions not conducive to high crop yields. Indeed, the price of grain in western Europe rose dramatically with the onset and continuance of the Little Ice Age. Perhaps the difficult conditions in Europe at that time encouraged emigration to North America.

By the time the wave of emigrants reached the Great Plains in the nineteenth century, conditions there had changed considerably from what had been typical in the thirteenth and fourteenth centuries. Instead of drought (which had terminated corn agriculture over a wide area), the high plains experienced comparatively heavy rainfall. One study has shown that in the nineteenth century the high plains had up to 30 percent more rainfall than is currently normal.[15] North of Texas, the plains were cooler in all seasons than they are now, but the Great Basin was warmer. This rainier, cooler climate on the plains made possible a "sea of grass," which in turn supported enormous herds of bison.

A question naturally arises: With the return of ample precipitation to the plains, why didn't corn agriculture return? I don't know the answer, but I suspect that part of the reason lies in the erratic behavior of the weather during periods of dynamic instability and blocking. We know that in the plains region such periods are characterized both by weeks of intense drought and intervals of heavy rain. Such conditions render corn farming hazardous; during periods of drought the likelihood of widespread grass fires was greatly increased.

As the Euroamerican settlers moved west, they resettled the regions abandoned by the farmers of seven centuries earlier; as they leapfrogged to the West Coast and pushed into the cordillera, the climate once again started to change. The Little Ice Age was ending.

Fortunately we have excellent weather records for the West in the nineteenth century. With the westward course of empire went the United States Army, including its surgeons, among whose duties was keeping records of regular weather observations. The quality of their observations was generally high, for enlightened men of the nineteenth century knew that there was a relationship between climate and health.[16]

The data of the 1850s period, for example, show that Taos, New Mexico, had about the same summer rainfall then as Madison, Wisconsin, has now. I know that if I didn't mow my lawn all summer, it would be "stirrup high," as the grasses of the West were often described in the central high plains and parklands. If we consider the carrying capacity for cattle, we can then estimte the impact of the 20 to 30 percent decrease of precipitation on the high plains that has occurred between the 1850s and the present time.

According to one estimate, fifteen inches of rainfall per year on a good range in good condition will support five animals per acre.[17] If the rainfall decreases to ten inches per year (a percentage of change that occurred in large areas in the late 1800s), the range will be overstocked, for with that amount of rain it will support only two to three animals per acre. The condition of the range could easily deteriorate to an average carrying capacity of one animal on an area that once held five.

All other factors being constant, such a diminution of carrying capacity would also reduce bison herds by three-quarters or so—but other factors were not constant. Intense hunting pressure was applied at the same time that the herds were in serious trouble because of climatic change. This combination eliminated the bison on the high plains as an important food source and a significant element in the environment.

Another example of the effect of climatic change on the Great Plains may be observed in the eastward extension of chinook patterns. In Ellis County, Kansas, the wheat yield dropped from approximately fifteen bushels per acre in the 1870s to about nine bushels in the 1890s, and corn yields dropped from about thirty bushels per acre to about twelve.[18]

THE FUTURE

The dispassionate observer is always fascinated by the regularity with which human beings rationalize their behavior on the basis of images, perceptions, and theories rather than facts. Examples abound. The perception of the western plains as a sea of grass supporting enormous herds of grazers hunted by horse-riding nomads was a subjective image of a transient piece of history. Equally unrealistic were the estimates of how many acre-feet of water in the Colorado basin could be divided up among potential users.

Similarly, Americans have been misled by the incorrect but widely held theory that climate does not change, or changes so slowly that man can always adjust. Couple this notion with the image of technologically self-confident man: whatever the contingency, his technological genius will enable him to prevail over perceived climatic deficiencies. His ingenuity is revealed in such different responses as the invention of barbed wire or cloud seeding.

Would barbed wire have held the enormous herds of bison? I doubt it. Their disappearance had to come first.

Will cloud seeding break a drought caused by the prevalence of extended, cloudless skies and dry chinook air?

Can irrigation canals, dams, pump storage, and bureaucracy provide 115 percent of the normal flow of the Colorado River for apportionment?

According to Frederick Jackson Turner, the unique nature of the American frontier shaped the personality of the nation. The study of environmental history shows that the nature of the West is closely tied to its varying climate. It is clear that in this region climate may change significantly, sometimes rapidly, and stay changed long enough to alter the character of human occupance.

As the people of the West push against the capacity of the land to support its particular material culture, the fluctuations of the carrying capacity in response to climatic variations become more critical. As the world becomes more heavily populated, the role of the West in food production becomes more important. We may be certain that in the future the climate of the West will vary, as will its economic base.

Will we enter the future armed with facts, or will we be encumbered with quaint perceptions and false theories?

NOTES

1. Lorin Blodget, *Climatology of the United States and of the Temperate Latitudes of the North American Continent* (Philadelphia: Lippincott, 1857).

2. John R. Borchert, "Climate of the Central North American Grassland," *Annals of the Association of American Geographers* 40 (1950): 1–39.

3. The synoptics and cordilleran climatology of these routes are discussed primarily in V. L. Mitchell, "The Regionalization of Climate in Montane Areas" (Ph.D. diss., University of Wisconsin–Madison, 1969).

4. Climatic implications east of the Rockies are discussed in Reid A. Bryson, "Airmasses, Streamlines, and the Boreal Forest," *Geographical Bulletin* 8 (1966): 228–69.

5. Reid A. Bryson and W. P. Lowry, "Synoptic Climatology of the Arizona Summer Precipitation Singularity," *Bulletin of the American Meteorological Society* 36 (1955): 329–99. This increase in dewpoint of the air before the onset of the summer rains is the basis for the old Zuni proverb: "When the Apache scalplocks on the wall of the kiva feel damp, the rains will come." The underground kiva wall is cool, the hair is slightly hygroscopic, and the two facts combine to make a "critical dewpoint indicator."

6. Though this is suggested in Reid A. Bryson, "The Lessons of Climatic History," *Environmental Conservation* 2 (1975): 163–70, a more thorough scientific justification is to be found in V. Y. Sergin, "On the Similarity of Changes in the General Atmospheric Circulation in the Course of Annual and Climatic Fluctuations," *Geofisica Internacional* 16 (1976): 133–49.

7. The original work was reported in Reid A. Bryson, W. N. Irving, and J. A. Larsen, "Radiocarbon and Soils Evidence of Former Forest in the Southern Canadian Tundra," *Science* 147 (1965): 46–48. The study was extended to cover a much larger area in Curtis J. Sorenson, J. C. Knox, J. A. Larsen, and Reid A. Bryson, "Paleosols and the Forest Border in Keewatin, N.W.T.," *Quaternary Research* 1 (1971): 468–73. Other studies by Sorenson and Knox extend the area into Mackenzie District. During the course of the original work, Dr. William Irving, an archaeologist, excavated some multiple soil horizons, such as the exposure at Black Fly Cove, Ennadai Lake, N.W.T., and found that artifacts of southern or Indian affinities were found in the forest soils, while northern or Eskimo affinity artifacts were found in the tundra soils. Evidently the historic association of Chipewyan with the forest and Caribou Eskimo with the tundra has a four-thousand-year basis.

8. P. Bergthorsson, "An Estimate of Drift Ice and Temperature in Iceland in 1,000 Years," *Jokull* 19 (1969): 94–101; H. H. Lamb, *The Changing Climate* (London: Methuen, 1966); A. M. Swain, "Environmental Changes during the Past 2,000 Years in North-Central Wisconsin," *Quaternary Research* 10 (1978): 55–68. The qualitative conclusion of this paper with respect to the period around A.D. 1200 is corroborated by J. C. Bernabo's unpublished quantitative results from Michigan.

9. Numerous papers by Waldo R. Wedel deal with this matter; for example, see *Prehistoric Man on the Great Plains* (Norman: University of Oklahoma Press, 1961).

10. David A. Baerreis and Reid A. Bryson, "Climatic Change and the Mill Creek Culture of Iowa, Part 1," *Journal of the Iowa Archaeological Society* 15 (1968). A summary is contained in Reid A. Bryson and Thomas J. Murray, *Climates of Hunger* (Madison: University of Wisconsin Press, 1977).

11. David A. Baerreis and Reid A. Bryson, "Dating the Panhandle Aspect Cultures," *Bulletin of the Oklahoma Anthropological Society* 14 (1966): 105–16.

12. A summary may be found in chapter 7 of Jesse D. Jennings, *Prehistory of North America* (New York: McGraw-Hill, 1968).

13. Bryson and Murray, *Climates of Hunger*, p. 76.

14. T. J. Blasing, "Methods for Analyzing

Climatic Variations in the North Pacific Sector and Western North America for the Last Few Centuries" (Ph.D. diss., University of Wisconsin–Madison, 1975).

15. E. W. Wahl and T. L. Lawson, "The Climate of the Mid-Nineteenth Century United States Compared to the Current Normals," *Monthly Weather Review* 98 (1970): 259–65.

16. E. W. Wahl, "A Comparison of the Climate of the Eastern United States during the 1830s with the Current Normals," *Monthly Weather Review* 96 (1968): 73–82.

17. See, for example, the figures given on p. 463 of the 1941 Yearbook of Agriculture, *Climate and Man.* This rationale has also been checked with a distinguished plant ecologist, Grant Cottam.

18. Theodore Rosenof, *Cultural Sensitivity to Environmental Change: The Case of Ellis County, Kansas, 1870–1900,* University of Wisconsin Institute for Environmental Studies Report no. 5 (Madison, 1973). It is an interesting coincidence that as decreased rainfall created a more steppelike condition in western Kansas, the ethnicity of much of the Ellis County population shifted from British to German-Russian stock.